WP-3

EMSP
Environmental Management Science Program
Project Summary Fact Sheet • October 1999

DETERMINATION OF SUBSURFACE DENSE NONAQUEOUS PHASE LIQUID (DNAPL)

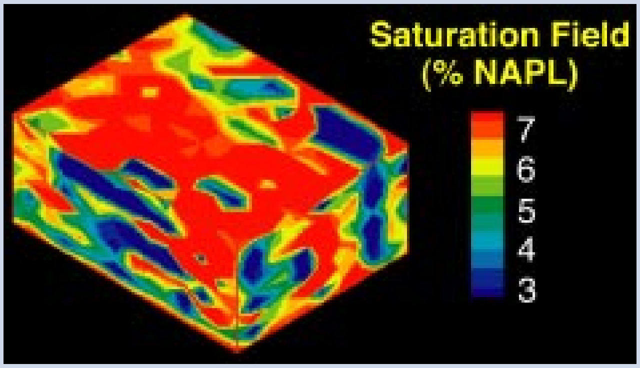
LOCATING AND UNDERSTANDING THE MIGRATION AND ENTRAPMENT OF DNAPL WILL HELP IMPLEMENT EFFECTIVE TREATMENT AND REMOVAL TECHNOLOGIES DIRECTLY TO THE SOURCE ZONE

The thin, discrete nature of DNAPL source zones at U.S. Department of Energy (DOE) sites presents a significant need to develop cost-effective DNAPL characterization tools. Current detection techniques such as core sampling and analysis, soil gas analysis, monitoring well sampling, and cone penetrometer testing fail to effectively determine the areal distribution and quantity of DNAPL. The ineffectiveness of the current point-measurement, hit-or-miss techniques is exemplified by the experience of drilling 300 boreholes in a sandy aquifer at Savannah River Site (SRS) and 200 boreholes in a fracture at Oak Ridge before DNAPL was identified. Furthermore, most intrusive characterization tools are of limited use because of the risk of mobilizing DNAPL.

The challenging problem of spatially determining the location and volume of DNAPL in saturated and unsaturated zones is being addressed by several EMSP research projects employing complementary approaches. The approaches encompass:

- improving understanding and application of subsurface imaging techniques by developing algorithms for processing measurement results from such noninvasive techniques as electromagnetic induction and induced polarization (IP);
- exploring the use of partitioning tracers in heterogeneous media combined with advanced modeling analysis to predict DNAPL distribution in three dimensions;
- understanding the coupled effect of physical and chemical heterogeneity on migration and entrapment of DNAPL to refine multiphase flow simulators; and
- applying geophysical techniques to analyze whether organic contamination is adsorbed on the surface or in the pore volumes to aid in flow and transport modeling.

Enabling the determination of DNAPL location and volume and improving the understanding of flow and transport properties will help in implementing effective treatment and removal technologies directly to the source zone, thus eliminating the long-term effect of groundwater contamination resulting from the slow processes of infiltration, percolation, vapor phase transport, and dissolution.



Partitioning Tracers
The University of Texas – Austin and coworkers team is focused on interwell tests to provide a spatially integrated measure of the DNAPL volume present in the tracer flow domain. The figure above shows the NAPL saturation distribution estimated from partitioning tracer data for the Hill Air Force Base OU1 field test.

PROBLEMS/SOLUTIONS

- Noninvasive means of using geophysical techniques with advanced data processing algorithms are needed to determine DNAPL contamination without risking its mobilization.
- Geophysical and partitioning tracer techniques are needed to delineate the areal extent of DNAPL contamination with the required spatial resolution.
- The ability to predict the distribution of DNAPL by quantifying the influence of subsurface chemical heterogeneity (wettability and interfacial tension) on hydraulic and entrapment properties must be improved.
- Understanding and modeling the sorption process of DNAPL with the aid of dielectric and nuclear magnetic resonance (NMR) measurements will aid in determining DNAPL mobility.

ANTICIPATED IMPACT

- Many DNAPL-related DOE site needs will be addressed: eight for source characterization, seven for source containment, and nine for source remediation.
- Cost-effective characterization and cleanup of major DNAPL contamination at Oakland, Oak Ridge, Richland, and SRS will be achieved. For example, more than 1,500 acres are affected by the DNAPL-contaminated groundwater plume at the SRS A/M Area, and more than 2,000,000 Kg of TCE is suspected to have been released at Paducah.
- Effective remedial measures for cleanup of DNAPL source zones will eliminate the long-term source for groundwater contamination and thus reduce the risk of human exposure.
- Significant costs from long-term treatment and compliance operations will be avoided. For example, \$50 M - \$70 M is estimated for operating the pump and treatment operation at the Hanford 200 Z and P Plant Aggregate Areas for a 33- to 56-year period, and annual compliance monitoring is estimated to cost \$2 M at SRS.

Technical Summary and Progress

Project Teams
Lead Principal Investigator (Award Number)

- University of Michigan
  PI: Linda M. Abriola (54680)
- University of British Columbia
  PI: Rosemary Knight (54699)
- University of Arizona
  PI: Mark L. Brusseau (54908)
  Pacific Northwest National Laboratory
- Lawrence Livermore National Laboratory
  PI: James G. Berryman (55011)
- University of Texas – Austin
  PI: Gary A. Pope (55216)
  Texas A&M University
  Duke Engineering Services, Inc.
- Massachusetts Institute of Technology
  PI: F. Dale Morgan (55300)
  Boston College

Geophysical Imaging Techniques

The Massachusetts Institute of Technology/Boston College team aims at understanding spectral IP as applied to mapping and characterizing contaminant plumes. Research was completed in studying the effects of solution chemistry and microgeometry on the spectral IP response of sandstones, and in developing three-dimensional and two-dimensional spectral IP modeling and inversion codes for an apparent grain size distribution. The methodology was applied to image the light NAPL plume (benzene and ethylene dibromide) at Massachusetts Military Reservation and will be applied to a Superfund site with DNAPL contamination in Massachusetts.

The Lawrence Livermore National Laboratory team is advancing the use of surface and borehole electromagnetic induction techniques by developing and applying algorithms for inverting magnetic field data to produce enhanced images of electrically conducting fluids underground, allowing better localization of contaminants for subsequent remediation efforts. The forward and inverse modeling capabilities were refined through testing and applications to field data already acquired. Field tests will be conducted using improved modeling capabilities at the Southern Edison pole yard in Visalia, California, which is contaminated with creosote and is under steam remediation.

Partitioning Tracers

Two projects are using partitioning tracers as an in-situ method for determining DNAPL in heterogeneous media. The University of Arizona/Pacific Northwest National Laboratory team is integrating the use of tracers with intermediate-scale flow cell experiments, physical measurement systems for water and DNAPL (including dual-energy gamma radiation), and an advanced modeling simulator (STOMP). A significant finding from a controlled field-scale experiment is that the tracer tests demonstrated the potential to accurately measure water content at the field scale. Also studied was a suite of tracers for partitioning coefficients and quantitative breakthrough responses at the intermediate flow cell. The improved STOMP flow and transport simulator is being used to simulate data collected from the flow-cell studies.

The University of Texas – Austin/Texas A&M University/Duke Engineering Services team is focused on interwell tests to provide a spatially integrated measure of the DNAPL volume present in the tracer flow domain. Progress to date includes the following: inverse modeling for estimating the distribution of permeability, porosity, and saturation; studies of tracer response and modeling of the transport by UTCHEM in a single fracture; application of state-of-the-art thermodynamic models to determine light NAPL fractions impacted by remediation at Kirkland Air Force Base; development of a new method for estimating partitioning coefficients in complex DNAPL such as coal tar; and performance of error analysis of the uncertainty in the saturation estimates to as low as 0.01 percent from interwell tracer tests.

Migration and Sorption of DNAPL

The University of Michigan team is investigating the influence of subsurface chemical heterogeneity (wettability and interfacial tension) on DNAPL migration and entrapment. Experimental research efforts are focused on DNAPL hydraulic property measurement and two-dimensional infiltration experiments for variously wetted synthetic and natural porous media. Theoretical models to quantify and describe the hydraulic property relations have been developed and incorporated into a two-dimensional numerical simulator. This simulator is being used to simulate experimental systems, as well as the coupled influence of physical and chemical heterogeneity on DNAPL migration at larger scales.

The University of British Columbia team is trying to answer whether geophysical techniques can be used to determine the pore-scale location of an organic contaminant; that is, whether it is adsorbed to the solid surface or carried in the fluid phase. Various surface states—water-wet, hydrophobic, oil-wet, controlled levels of oil adsorption—of natural sand, pure quartz sand, silica gel, and kaolinite have been prepared, and NMR and dielectric measurements were completed on these samples to characterize the effect of adsorbed oil (the contaminant of interest). While the dependence of dielectric measurements on the presence of adsorbed oil is a fairly simple relationship, the interpretation and modeling of the NMR data have required a detailed study of the effect of naturally occurring paramagnetic forms of iron on the measured NMR parameters.

For additional information about the EMSP, please contact one of these representatives:

Mark A. Gilbertson
Director, Office of Science & Risk
(202) 586-7150
emsp@id.doe.gov
www.em.doe.gov/science

Tom Williams
EMSP Director, DOE-ID
(208) 526-2460
emsp@id.doe.gov
www.id.doe.gov/emsystems/emsp

Roland Hirsch
EMSP Director, Office of Science
(301) 903-9009
emsp@id.doe.gov
www.er.doe.gov